Mechanics Transport Communications

Academic journal http://www.mtc-aj.com

ISSN 1312-3823 (print)
ISSN 2367-6620 (online)
volume 22, issue 3/2, 2024
article № 2531

DEVELOPMENT OF AN INTEGRATED METHOD OF GENERATION OF ENSEMBLES OF COMPLEX SIGNALS WITH OPTIMIZED PARAMETERS OF MUTUAL CORRELATION OF PSEUDO-RANDOM SEQUENCES

Oleksii Komar[1], Olena Syvolovska[2], Galina Cherneva[3]
oleksiikomar3@gmail.com, ilyasvl95@gmail.com, cherneva@vtu.bg

[1] National Aviation University, Kyiv, Lubomyr Huzar ave., 1, UKRAINE
[2]Ukrainian State University of Railway Transport, Kharkiv, Feuerbach Square 7, UKRAINE
[3]Todor Kableshkov University of Transport, Sofia, Geo Milev Str. 158, BULGARIA

Key words: *cognitive radio, pseudorandom sequences, signal ensembles, mutual correlation, interchannel interference, electromagnetic compatibility, optimization techniques, signal detection.*

Abstract*: The article designates cognitive radio systems, which rely on the simultaneous operation of multiple signals, as the object of research. Ensuring electromagnetic compatibility among these signals emerges as critically important. The pressing issue addressed in this research is the necessity to reduce interchannel interference, which negatively impacts communication quality and increases energy expenditure. Addressing this problem requires the development of new methods to generate signal ensembles with optimized mutual correlation parameters of pseudorandom sequences, considering the dynamic nature of radio frequency environments.*

As a result of the research, a method and algorithm were proposed and implemented, allowing for the integrated optimization of these parameters to improve system efficiency. This method involves the use of sequences that minimize energy interaction, thereby reducing interchannel interference. The effectiveness of the developed method is due to its ability to enhance signal detection and decrease noise levels through the application of advanced algorithms, including heuristic and metaheuristic optimizers. Preliminary evaluation of the results demonstrates an increase in interference resistance and an improvement in decoding efficiency compared to traditional systems.

A distinctive feature of the proposed method is its flexibility and unpredictability, which allows for the optimization of signal configurations in varied operational conditions. The method can be applied in fields such as military radar, wireless networks, cognitive radio, and data transmission systems, where such capabilities significantly enhance operational efficiency and security.

INTRODUCTION

In the rapidly evolving field of telecommunications, the demand for efficient and interference-resistant communication systems is paramount. Cognitive radio systems, which operate by dynamically adapting to the environment to optimize frequency usage without interfering with licensed users, play a crucial role in modern communication. One of the primary challenges in advancing cognitive radio technology is the mitigation of interchannel interference, which significantly degrades communication quality and increases energy consumption.

The dynamic nature of the radio frequency environment, with its varying signal characteristics and interference levels, necessitates the development of sophisticated methods for generating signal ensembles. These methods must not only minimize energy consumption but also enhance the electromagnetic compatibility of simultaneous signals. Traditional methods often fall short in effectively handling the complexities of modern cognitive radio systems, leading to inefficient frequency distribution and reduced system performance.

This article focuses on developing and implementing innovative methods for generating ensembles of complex signals with optimized mutual correlation parameters of pseudorandom sequences. These methods aim to reduce interchannel interference and improve the overall efficiency of cognitive radio systems. By integrating advanced algorithms, including heuristic and metaheuristic optimizers, the proposed methods enhance signal detection capabilities and reduce noise levels, thereby significantly improving the robustness and reliability of communication systems.

THE MAIN PART

In the architecture of cognitive radio systems, which are engineered to manage multiple signals simultaneously, ensuring electromagnetic compatibility of these signals emerges as a paramount concern. The challenge is further intensified by the high peak values of the side lobes in mutual correlation functions, which are intrinsic to complex signal configurations. These peaks can escalate interchannel interference, detrimentally impacting communication quality, escalating energy expenditures, and leading to suboptimal distribution of radio frequencies.

Such exacerbation in interference levels calls for the development of novel signal ensemble generation methodologies. Traditional approaches often prove inadequate in addressing the intricacies associated with modern cognitive radio systems. This inadequacy is primarily due to their failure to adapt to the dynamic spectral environments, leading to inefficient frequency allocation and diminished system performance. Therefore, the evolution of cognitive radio architecture demands innovative solutions that can mitigate these challenges and enhance overall system efficiency. [1].

The development and implementation of a comprehensive method for generating ensembles of complex signals with optimized mutual correlation parameters of pseudorandom sequences enhances the overall efficiency of cognitive radio systems. This integrated method involves the use of sequences that ensure minimal energy interaction, thereby reducing the level of interchannel interference (Fig. 1).

The method is implemented using linear, nonlinear, and recursive pseudorandom sequences, which ensures high signal coding efficiency, enhancing immunity to interference, including interchannel interference, thereby reducing the likelihood of false identification at the receiver. [2,3].

Based on the diagram, the process is structured into three main stages, reflecting a systematic approach to optimizing the signal generation (Fig. 1).

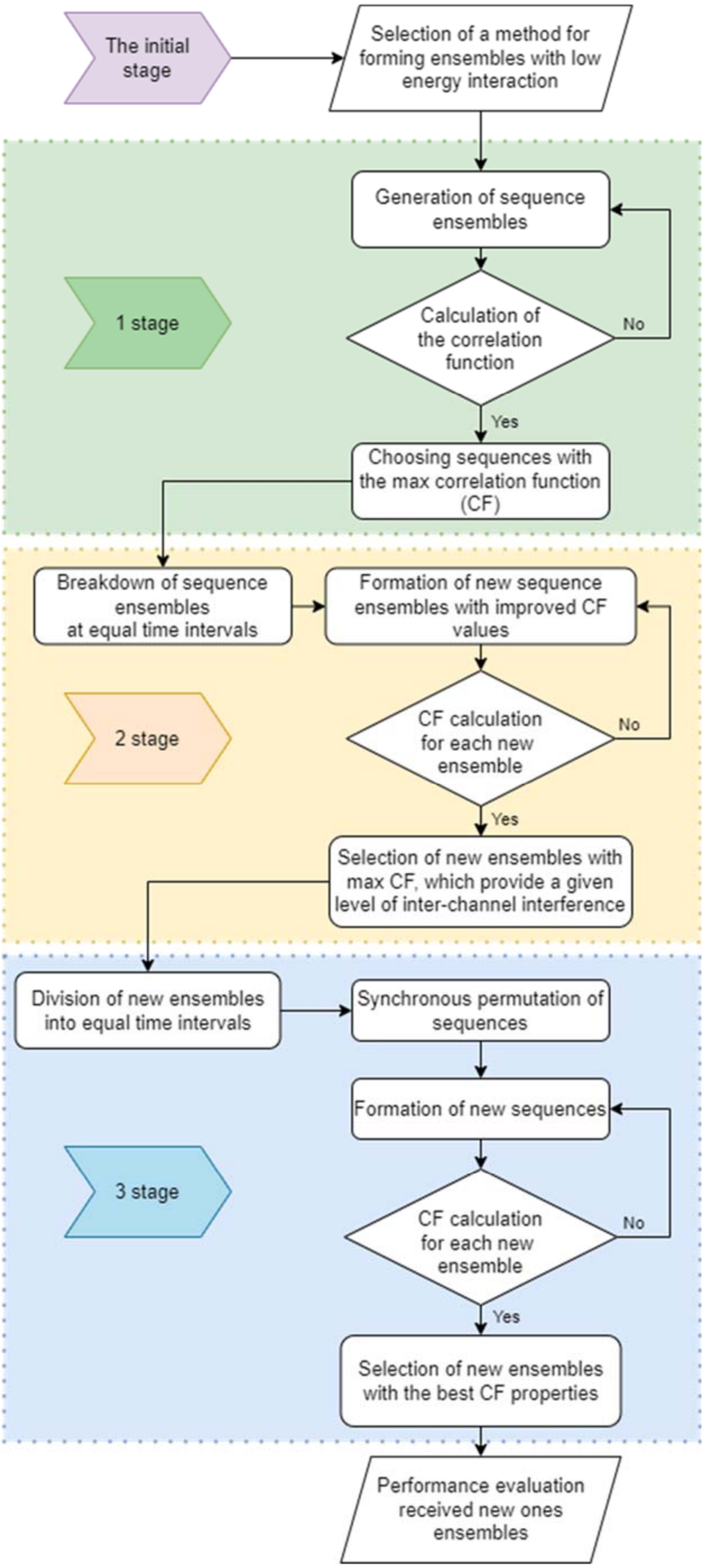

Fig. 1 – Algorithm of the method of generating ensembles of complex signals

First Stage. Initialization and selection of an assembly formation method from a pool of energy-efficient interactions. This stage ensures that the foundational sequences possess minimal mutual correlation, suitable for pulse sequence synthesis with minimized side lobes and correlation dependency.

Substantiated research into the properties of pseudorandom sequences can be conducted through analytical reviews and computer modeling to determine the optimal parameters of sequences that minimize energy interaction. Furthermore, the development of mechanisms to adapt the selection of sequences to changes in the radio frequency environment is essential. This adaptation will enhance the effectiveness of real-time communication.

Continuing from the first stage of the process where the initialization and selection of an assembly formation method ensure minimal mutual correlation, the next step involves a deeper analysis and refinement of these sequences. By utilizing sophisticated computer modeling techniques, researchers can explore the intricate behaviors of these sequences under various conditions, ensuring that the sequences not only meet the initial criteria of minimized side lobes and correlation dependency but are also robust against dynamic spectral changes. This proactive adaptation mechanism supports the cognitive radio systems' ability to perform reliably in diverse and fluctuating environments, thereby enhancing overall communication efficiency and system resilience.

Second Stage. New assemblies are developed at regular time intervals based on the effectiveness of mutual correlation values, ensuring that each new assembly meets or exceeds the required interference reduction standards. This is critical for maintaining system performance under varying channel conditions.

At the second stage of the method, the refined sequences of complex signal ensembles are divided into equal time intervals. [4,5]. Based on these intervals, through exhaustive search, new ensembles of sequences are formed with a low level of correlation dependence, ensuring a specified level of interchannel interference. As a result, the obtained ensembles of complex signals exhibit low values of maximum amplitudes of side lobes in the correlation functions, which provides high interference resistance, a high probability of signal detection in conditions of interchannel interference, and a sufficiently uniform distribution, thereby ensuring high decoding efficiency.

Optimization at this stage of the algorithm is possible through the use of heuristic methods, including genetic algorithms or metaheuristic optimizers, to select the optimal time intervals and structure of the ensembles. Additionally, it is necessary to analyze the impact of the electromagnetic environment by assessing how external interference and noise levels affect the signal ensembles and how this can be minimized.

Third Stage. The process involves a synchronous permutation of sequences and the formation of new sequences, which are assessed for their mutual correlation to ensure compliance with the minimal side lobe criteria. This cyclic optimization helps in fine-tuning the ensemble properties to match the dynamic environmental conditions more accurately.

At the third stage of the method, sequences that have been enhanced through the approach described earlier—namely, sequences with minimal energy interaction and low levels of interchannel interference—are again segmented into equal time intervals, which differ from the previous step. The time intervals of all sequences are rearranged synchronously to form new sequences. In this process, it is mandatory to meet the requirement for mutual correlation, meaning the new sequences must exhibit low levels of peak side lobe values in the mutual correlation functions.

This reconfiguration step is critical as it ensures that the optimized sequences do not revert to states that could potentially increase correlation errors or lead to signal overlap, which could compromise system efficiency and accuracy. By systematically rearranging the sequences within new time intervals, the method promotes the continuous dynamic adaptation of the signal ensemble. This dynamic adaptation is crucial for maintaining system robustness in fluctuating electromagnetic environments and for enhancing the cognitive radio's ability to handle diverse operational scenarios. Moreover, this stage of the process leverages advanced signal processing techniques to further refine the signal structure, thus minimizing potential interference and maximizing the overall reliability and throughput of the communication system. These strategic adjustments are aligned with the principles of modern digital signal processing, which emphasize the importance of adaptive methodologies in managing complex signal environments effectively.

The effective management of these stages, supported by the algorithm's structured approach, ensures the adaptability and scalability of the cognitive radio systems, making them robust against environmental changes and capable of reducing potential misidentification risks significantly.

Let us consider in more detail the algorithmic approach of the initial stage of the integrated method of generating ensembles of complex signals with minimal energy correlation based on pseudorandom sequences. The growing needs in modern telecommunication systems, particularly the necessity for multiple access by subscribers, necessitate the development of advanced methods for synthesizing ensembles of coded signals. These methods are not only required to reduce the energy impact between channels but also to expand the volume of complex signals while simultaneously improving their mutual correlation properties [6,7].

Traditional approaches to distributing user signals, such as frequency division or time division, although widely used in practice, face limitations due to the constrained frequency-time resources. These methods do not allow for the creation of large-scale signal ensembles without significantly increasing the level of interchannel interference, adversely affecting the overall effectiveness of the data transmission systems. [2,3].

An alternative approach involves the use of high-resolution antennas. Although this approach provides spatial selection of signals, it is not without drawbacks. Such technical solutions can be complex in manufacturing, deployment, and operation, and may not always be effective in the context of developing cognitive radio networks, which require a high degree of availability and flexibility [8].

Given these limitations, there is a compelling need to implement new methods for forming signal code ensembles, specifically—a method based on the formation of code ensembles using random/pseudorandom signals with low levels of energy interference.

The aim of the method is to create diverse signal configurations to enhance their correlation properties and to increase the volume of complex signal ensembles while simultaneously improving their mutual correlation characteristics. This method serves as an alternative to frequency division, time division, and spatial selection of signals, which are often limited by frequency-time resources or the complexity of antenna systems. It is based on the use of complex signal code ensembles with sequences optimized for minimizing interchannel interference. [6,7].

Furthermore, this approach reduces the predictability and enhances the security of the signals from unauthorized interference or interception. It is founded on the generation of random or pseudorandom numerical sequences used to initiate intervals between signals in the ensemble. These sequences form the basis for creating an unpredictable signal structure, thereby increasing their effectiveness in various applications.

By leveraging the properties of pseudorandom sequences, this method effectively harnesses stochastic properties to ensure that each signal within the ensemble maintains a unique pattern. This uniqueness significantly reduces the probability of signal collision and interference, thereby enhancing the robustness and reliability of communication in densely populated signal environments. Moreover, the ability to dynamically adapt the intervals based on real-time environmental and operational conditions allows cognitive radio systems to maintain optimal performance even under varying electromagnetic conditions. This adaptability is crucial for systems operating in dynamic and unpredictable environments, making the proposed method particularly valuable for next-generation telecommunication networks.

Key advantages of the method.

1. Diversity and unpredictability. Utilizing random or pseudorandom sequences generates a vast array of unique signal configurations. This high level of diversity complicates the ability of unauthorized entities to analyze or intercept these signals. From a cryptographic perspective, the unpredictability inherent in these sequences makes them ideal for securing communications in environments susceptible to eavesdropping and signal jamming, enhancing the cryptographic strength of the system.

2. Flexibility. The method enables the flexible customization of ensemble parameters to suit specific operational needs by altering sequence lengths, the number of pulses, or the intervals between them. This adaptability is crucial for systems requiring dynamic response capabilities, such as adaptive communication systems in fluctuating environments, where conditions such as signal congestion or interference levels may vary significantly.

3. Improvement of correlation properties. The non-periodicity and unpredictability in the timing of the intervals improve the autocorrelation and cross-correlation properties of the signals. This enhancement reduces the likelihood of correlation peaks that could lead to predictable patterns, thereby minimizing the error rates in signal transmission. Improved correlation properties are critical in applications requiring high signal clarity and precision, such as satellite communications and deep-space data transmissions.

4. Broad industry applications. The method is applicable across various sectors, including military radar systems, where robust and secure communication is critical; wireless networks that benefit from efficient frequency use; cognitive radio systems that adapt to changing environmental conditions; and data transmission systems where large volumes of data require reliable and secure handling.

Characteristics of random/pseudorandom sequence methods.

1. Length of sequences. This determines the number of pulses and their timing within the transmission window. The sequence length impacts the bandwidth and the power spectrum of the signal, influencing both the coverage range and the resolution of the communication system.

2. Intervals between impulses. These vary based on the sequences generated, contributing to the ensemble's diversity. By adjusting these intervals, systems can better manage the spectral spacing between signals, optimizing the use of available bandwidth and reducing the likelihood of signal overlap and interference.

3. Correlation properties. These depend on the selection of sequences and the methods of their permutation. Effective management of correlation properties ensures that the signal ensemble can achieve minimal cross-correlation, which is crucial for reducing system noise and enhancing signal integrity.

The generalized algorithm for forming complex ensembles of coded signals through the use of pseudorandom sequences with minimal energy overlap is depicted in Fig. 2. This algorithm includes steps for optimizing the energy efficiency of signal interactions, which is fundamental in reducing power consumption and extending the operational lifetime of battery-powered devices such as mobile phones and remote sensors. This strategy is particularly beneficial in dense network environments like urban areas, where energy efficiency and interference management are paramount.

By integrating these principles, the method not only supports robust and secure communication but also aligns with contemporary needs for sustainable and efficient telecommunications infrastructure.

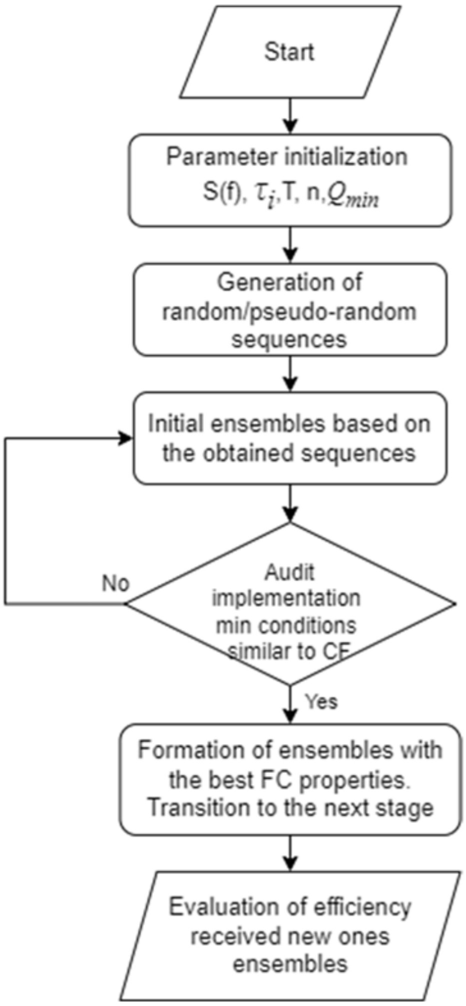

Fig. 2 – Generalized algorithm of the method of synthesis of ensembles of code signals with minimal energy overlap

The step-by-step generalized algorithm for the practical implementation of the method of synthesis of code signal ensembles contains the following stages.

1. Parameter Initialization: Set the number of sequences *N*, the duration of pulses τ_i, the total length of the sequence T_i and the minimum spacing between pulses $Q_{min.}$ This step is crucial for defining the structural framework of the signal ensemble, ensuring that all sequences are generated within defined spectral and temporal limits, which aids in maintaining system integrity and preventing signal overlap.

2. Generation of Pseudorandom Sequences. Generate pseudorandom sequences to determine the intervals between pulses. The use of pseudorandom sequences is integral for creating irregular, non-repetitive patterns that enhance security and complexity, making the signals less susceptible to interception and analysis.

3. Formation of Initial Signal Ensembles: Form initial ensembles based on the generated sequences. This step involves the actual assembly of the signal structures that will be tested for performance and interference levels, providing a base configuration for further optimization.

4. Determination of the Mutual Correlation Function (MCF). Analyze the correlation profile of the signals to assess how well the components of the ensemble interact. This analysis is critical for identifying undesirable correlations that could lead to interference and reduced clarity in signal transmission.

2-5. Optimization of the Ensemble. Optimize the ensemble to achieve minimal correlation among its components by removing or replacing elements that do not meet the condition. This optimization process is pivotal in refining the signal ensemble to ensure that it meets the required specifications for minimal interference and optimal performance.

5. Final Formation of the Signal Ensemble. Once satisfactory correlation properties are achieved, finalize the ensemble of signals. This step solidifies the ensemble configuration that will be deployed in operational settings, ensuring that the ensemble is robust, efficient, and capable of functioning in diverse environmental conditions.

Steps 2-5 are repeated until the correlation properties meet the desired standards, ensuring that the ensemble is continually refined to adapt to new findings and improvements during the optimization process.

The use of advanced optimization algorithms, such as genetic algorithms or simulated annealing, in Step 5 enhances the ability to find globally optimal solutions that might not be evident through standard analytical methods. These algorithms are particularly effective in large, complex systems where multiple parameters and constraints must be balanced.

To form ensembles of complex signals with minimal energy interference, various types of sequences such as linear, nonlinear, and recursive can be utilized [2,8].

1. Linear Sequences. These are generated using linear recursive generators. The principal idea is that each subsequent element of the sequence is computed as a linear combination of the previous elements. The general formula for such a sequence is depicted as:

$$x_n = \left(a_1 \cdot x_{n-1} + a_2 \cdot x_{n-2} + ...a_k \cdot x_{n-k}\right) \bmod M \ , \qquad (1)$$

where x_n – is the nth element of the sequence, a_1 a_2 a_k – are the coefficients, M – is the modulus, k – is the order of the sequence.

This type of sequence is particularly valued for its predictability and regularity, which are advantageous in environments where signal interference needs to be carefully managed to avoid cross-talk and ensure clear communication channels.

2. Nonlinear Sequences. These are generated using nonlinear functions, such as those based on chaotic systems. This allows for the creation of signals with diverse and complex characteristics, such as nonlinearity, randomness, and chaotic behavior. Nonlinear sequences are beneficial in scenarios where enhanced security and robustness against pattern recognition and signal interception are required, making them suitable for secure communication applications.

3. Recursive Sequences. These sequences are generated using recursive relations, where each subsequent element is determined through one or more previous elements according to a set of rules. They are similar to linear sequences but their formula is more complex and contains nonlinear components. Recursive sequences are used to create sequences with minimal energy interference, as they can be designed to optimize phase cancellation and reduce the power of unwanted spectral components.

Table 1 would typically include examples and classifications of these sequences to provide a clearer understanding of their applications and effectiveness in different settings.

Table1 - Examples of the most common sequences

Linear Sequences	Nonlinear Sequences	Recursive Sequences
M-Sequences	Galois Sequences	Sequences with Unique Bit Density
Gold Sequences	Hammer-Wu Sequences	Linear Recursive Sequences
Kasami Sequences	Mac-Climent Sequences	Fibonacci Sequences
Pseudorandom Noise Sequences	Sequences with Balanced Properties	Sequences with Nonlinear Recursive Relations
Barker Sequences	de Bruijn Sequences	Recursive Sequences with Complex Properties
Lempel-Ziv Sequences	Nonlinear Random Sequences	Halton Sequences
Sequences Based on Nonlinear Recursive Relations	Sequences Based on Elliptic Curves	

The choice of sequence type impacts the spectral efficiency and the ability to handle multipath and fading effects in wireless communication. For example, linear and recursive sequences are generally easier to implement and analyze mathematically, making them suitable for systems where simplicity and reliability are crucial. On the other hand, nonlinear sequences, with their inherent complexity, offer advantages in security and noise resistance, making them ideal for military and financial communication systems where privacy and data integrity are paramount.

By strategically selecting the type of sequence and tailoring the sequence parameters to the specific needs of the communication environment, engineers can significantly enhance the performance and reliability of modern telecommunication systems. This methodological flexibility is essential for adapting to the rapidly evolving technology landscape and meeting the increasing demands for higher data rates and more reliable connections in congested networks.

In the formation of complex signals, nonlinear and recursive methods are most commonly used due to their high entropy and unpredictability, which provide enhanced security and resistance to interference in smart radio systems and cryptography. These attributes are crucial for maintaining the integrity and confidentiality of communications in environments prone to eavesdropping and signal jamming.

The initial step in the method of forming ensembles of complex signals with minimal energy interference is the procedure of decomposing code sequences into time intervals. This decomposition serves as the foundation for creating primary signal structures, which then undergo an optimization process in subsequent stages. This optimization includes the permutation of sequences, assessment of correlation properties, and correction aimed at achieving optimal characteristics.

Nonlinear and recursive methods are favored in advanced signal processing due to their ability to generate sequences that are less predictable and more complex than those produced by linear methods. This complexity is derived from the inherent mathematical properties of the sequences which include chaotic behavior and deep structural recursion, making the sequences difficult to predict or replicate without detailed knowledge of the initial conditions and generating algorithms.

The decomposition of sequences into time intervals is a critical process that helps in isolating and identifying unique signal characteristics that can be fine-tuned for specific applications. By segmenting the sequences, engineers can apply targeted adjustments to enhance certain features of the signal, such as its spectral efficiency or its robustness against noise and interference.

During the optimization phase, permutation techniques are employed to rearrange the sequence elements in a way that minimizes the correlation between them, effectively spreading the energy of the signal across a wider spectrum and reducing the likelihood of interference peaks. This step is essential for systems where signal clarity and precision are paramount, such as in satellite communications and deep-space telemetry.

Evaluating and correcting the correlation properties ensures that the ensemble not only meets the technical requirements for transmission but also adheres to security standards necessary for encrypted communications. By continuously refining these properties, the method supports the creation of highly efficient and secure signal ensembles suitable for high-stakes applications in military, finance, and government communications.

CONCLUSIONS

The development and implementation of the integrated method for generating ensembles of complex signals with minimized energy correlation, as described in this article, marks a significant advancement in cognitive radio technology. By leveraging pseudorandom sequences to optimize the mutual correlation parameters, this method effectively mitigates interchannel interference, enhancing the efficiency and reliability of communication systems. The use of advanced algorithms, including heuristic and metaheuristic optimizers, further refines the signal's resistance to noise and external disturbances, ensuring robust operational performance across various communication environments. The adaptability and scalability of this approach provide a substantial improvement over traditional frequency allocation methods, making it an invaluable asset in the continual evolution of telecommunication systems.

LITERATURE

[1]. Syvolovskyi, I. M., Lysechko, V. P., Komar, O. M., Zhuchenko, O. S., Pastushenko, V. V. Analysis of methods for organizing distributed telecommunication systems using the paradigm of Edge Computing. 2024. *National University «Yuri Kondratyuk Poltava Polytechnic». Control, Navigation and Communication Systems*, 1(75), P. 206-211 DOI: 10.26906/SUNZ.2024.1.206

[2]. Lysechko V. P., Stepanenko Y.G. Method for Combating Intrasystem Interference in Code Division Multiple Access Communication Systems. Radioelectronic and Computer Systems, Scientific and Technical Journal, Kharkiv: «KhAI,» 2010. Issue 5(46). P. 277–281.

[3]. Indyk S. V., Lysechko V. P., Zhuchenko O. S., Kitov V. S. The formation method of complex signals ensembles by frequency filtration of pseudo-random sequences with low interaction in the time domain. Radio Electronics, Computer Science, Control. 2020. Issue 4 (55). P. 7 – 15. DOI 10.15588/1607-3274-2020-4-1.

[4] Althunibat, S., Narman, H.S., Zahmatkesh, H. Cognitive radio-based spectrum sensing under different primary user traffic models. EURASIP J. Wireless Comm. and Networking 2014, 149 (2014). DOI: 10.1186/1687-1499-2014-149.

[5] Mustapha, M., Abdulhasan, R., Faeq, A.K., et al. Adaptive inter-channel interference mitigation in OFDM systems using cognitive radio-based models. Wireless Personal Communications 99, 1453–1468 (2018). DOI: 10.1007/s11277-018-5288-3.

[6] Liang, Y.-C., Zeng, Y., Peh, E.C.Y., Hoang, A.T. Sensing-throughput tradeoff for cognitive radio networks. IEEE Transactions on Wireless Communications 7(4), 1326-1337 (2008). DOI: 10.1109/TWC.2008.060869.

[7] Coulson, A.J. Blind Detection of Wideband Interference for Cognitive Radio Applications. EURASIP J. Adv. Signal Process. 2009, 727686 (2009). DOI: 10.1155/2009/727686.

[8] Wang, B., Liu, K.J.R. Advances in cognitive radio networks: A survey. IEEE Journal of Selected Topics in Signal Processing 5(1), 5-23 (2011). DOI: 10.1109/JSTSP.2010.2093210.

ИНТЕГРИРАН МЕТОД ЗА ГЕНЕРИРАНЕ НА АНСАМБЛИ ОТ СЛОЖНИ СИГНАЛИ С ОПТИМИЗИРАНИ КОРЕЛАЦИОННИ ПАРАМЕТРИ НА ПСЕВДОСЛУЧАЙНИТЕ ПОСЛЕДОВАТЕЛНОСТИ

Oleksii Komar[1], Olena Syvolovska[2], Galina Cherneva[3]
oleksiikomar3@gmail.com, ilyasvl95@gmail.com, cherneva@vtu.bg

[1] National Aviation University, Kyiv, Lubomyr Huzar ave., 1, UKRAINE
[2]Ukrainian State University of Railway Transport, Kharkiv, Feuerbach Square 7, UKRAINE
[3]Todor Kableshkov University of Transport, Sofia, Geo Milev Str. 158, BULGARIA

Ключови думи: *когнитивно радио, псевдослучайни последователности, сигнални ансамбли, взаимна корелация, междуканална интерференция, електромагнитна съвместимост, техники за оптимизиране, откриване на сигнали.*

Резюме: *Обект на изследване в доклада са когнитивните радиосистеми, които разчитат на едновременната работа на множество сигнали. Важен проблем в тях е осигуряването на електромагнитна съвместимост и намаляване на междуканалните смущения, които влияят отрицателно върху качеството на комуникацията и увеличават разхода на енергия. Решаването на този проблем изисква разработване на нови методи за генериране на ансамбли от сигнали с оптимизирани параметри на взаимна корелация на псевдослучайните последователности.*

В резултат на изследването са предложени и внедрени метод и алгоритъм, позволяващи интегрираната оптимизация на тези параметри за подобряване на ефективността на системата. Този метод включва използването на последователности, които минимизират енергийното взаимодействие, като по този начин намаляват междуканалните смущения. Ефективността на разработения метод се дължи на способността му да подобрява откриването на сигнали и да намалява нивата на шум чрез прилагане на усъвършенствани алгоритми, включително евристични и метаевристични оптимизатори. Предварителната оценка на резултатите показва повишаване на устойчивостта към смущения и подобрение на ефективността на декодиране в сравнение с традиционните системи.

Отличителна черта на предложения метод е неговата гъвкавост и непредсказуемост, което позволява оптимизиране на конфигурациите на сигнала в различни работни условия. Методът може да се прилага в области като военно дело, безжични мрежи, когнитивно радио и системи за предаване на данни, където такива възможности значително повишават оперативната ефективност и сигурност.